BELLCOMM, INC.
1100 Seventeenth Street, N.W.   Washington, D.C. 20036

SUBJECT: Weight Estimates of Common
Mission Module Structure
Case 730

DATE: December 14, 1967

FROM: C. E. Johnson

ABSTRACT

This memorandum discusses Common-Mission-Module
(CMM) configurations with respect to preliminary structural
weight estimates for various proposed missions. It is
concluded that a one-floor CMM is more advantageous weight-
wise (structural) than a two-floor CMM for missions
requiring 2 to 3 astronauts. Also, a two-floor CMM is more
advantageous weight-wise (structural) than a one-floor CMM
for missions requiring 4 to 12 astronauts. The penalty
associated with using one-floor mission modules on planetary
missions ($\gtrsim$ 4 astronauts) is approximately 4% or less of the

injected payload. Whereas, the weight advantage associated
with a 2 to 3 man CMM, for relatively short-lived lunar
bases, represents 5% or more of the landed payload, and
perhaps 25% of the useful payload.

BELLCOMM, INC.
1100 Seventeenth Street, N.W.   Washington, D.C. 20036

SUBJECT: Weight Estimates of Common
Mission Module Structure
Case 730

DATE: December 14, 1967

FROM: C. E. Johnson

MEMORANDUM FOR FILE

I. INTRODUCTION

In the planning of post Apollo manned space
activities, it has been proposed that as much use as
possible be made of all newly developed hardware and
spacecraft modules. In pursuing this goal, one mode of
advanced planning is to study the various proposed missions
and determine existing commonality; knowing this commonality,
it may then appear feasible to design and develop common
spacecraft hardware that would require a minimum of modifi-
cation, if any, for a particular mission.

This memorandum generally discusses Common-
Mission-Module (CMM) configurations with respect to
preliminary structural weight estimates for various proposed
missions. A matrix of proposed primary and secondard
advanced missions is shown in Table 1.

TABLE 1

PRIMARY

	Fly By	Orbital	Landing	Surface Shelter
Earth		x		
Mars	x	x	x	x
Moon		x	x	
Venus	x	x	x	

SECONDARY

	Fly By	Orbital	Landing	Surface Shelter
Mercury	x			
Jupiter	x			
Asteroids	x			

A basic CMM configuration is assumed in this memorandum (see Figures 1 and 2). In choosing this configuration it is not proposed that this is necessarily "the-way-to-go" but rather that it is representative weight-wise and a reasonable choice to establish as a focal point for further study.

II. ASSUMPTIONS:

The following assumptions were made in performing this study:

1. The maximum outer diameter of the CMM is 260 inches to insure compatibility with the SIVB stage of the SV launch vehicle without inducing a hammerhead condition during launch into Earth orbit.

2. The minimum free height between floors is 6 feet.

3. Living quarters entailing such functions as sleeping, recreation, personal hygiene, etc., are separate from spacecraft operations entailing such functions as command and control, laboratories, etc.

4. Spacecraft operations and command and control functions should be packaged in CMM operations quarters in a manner that is operationally efficient.

5. The CMM is pressurized at 7.5 psi.

6. A central passageway/airlock is required for crew transfer and for modular protection against spacecraft interior hazards.

7. Primary spacecraft control functions are centrally located in the central passageway and it will be further designed to serve (in part) as a shelter during extreme solar activity.

8. A meteoroid penetration criterion of
    $P(0) = 0.999$ is used.

9. The near-Earth Apollo meteoroid environment
    is used throughout all space other than the
    asteroid belt   (Reference 2).

10. The maximum MSC asteroid flux model, based
    on calculations of the Gegenshein pheonomenon,
    is used for asteroid shielding design.
    (Reference 3). Since the asteroid belt is
    directional, one-half of the CMM cylindrical
    surface area is assumed exposed to asteroidal
    impact.

III. CMM CONFIGURATION:

Various bulkheads can be used for the cylindrical
mission module shown in Figures 1 and 2. Some of the
configuration that can be considered are:

a. Flat plate,
b. Elliptical,
c. Hemispherical,
d. Toroidal (either circular or elliptical) and,
e. Scallop (see Figure 3, Reference 6).

In choosing the best configuration for a CMM, the bulkhead
weight must be traded off with respect to the weight of the
additional length of cylindrical section required, and also
with respect to commonality. It is not presently clear which
is the best bulkhead configuration for the CMM. Of the above
alternatives, however, the toroidal mission module/bulkhead
configuration (Figure 1 and 2) appears to be an interesting
prospect and is therefore assumed in this memorandum. A
problem may exist during launch into Earth orbit and perhaps
during other large propulsive maneuvers, due to the tendency
of a toroid to roll inside out when supported only around its
outside edge. However, this can be overcome by the use of
tension cables such as are shown in Figures 1 and 2. These
cables can readily be removed subsequent to launch into Earth
orbit or injection, thereby avoiding additional constraints
on the free movement of astronauts within the CMM. If
required they can be replaced for other propulsive maneuvers
such as retro-breaking, etc.

Various outer-wall skin configurations can be considered for a mission module. The design of the outer-wall must provide for the following functions:

1. Withstand launch loads,

2. Withstand CMM internal pressure,

3. Meteoroid/asteroid shielding,

4. Radiators, and

5. Thermal insulation.

The outer-wall configuration assumed in this memorandum is shown in Figure 4. It is composed of a truss-core sandwich separated from a "third" sheet. This configuration lends itself towards the support of launch loads through the truss core, and the CMM internal pressure through the third skin. It is an efficient structure for meteoroid shielding and, for preliminary design purposes, it can be idealized as a 3-sheet configuration by considering one-half the thickness of the core to be acting integrally with the thickness of the truss-core face sheets. Radiator tubing can be neatly attached to the outer truss-core face sheet running parallel to the core. An insulating material, such as multi-sheet insulation, can be easily accommodated between the truss-core and pressure wall of the CMM, correctly positioned behind the radiator. This configuration lends itself towards commonality in that the pressure wall can remain the same for all missions. Referring to Reference 7, concerning expected bumper thickness, it appears that the outer face sheet (bumper) can also reasonably remain constant. Therefore, it appears that the various meteoroid/asteroid design requirements can be satisfied, keeping the basic outer-wall geometry constant, by merely changing the thickness of the rear truss-core face sheet (0.05 inch < thickness < 0.5 inch). Futhermore, a common radiator can be designed to accommodate the above matrix of missions for a very small weight penalty (Reference 7).

IV. CMM STRUCTURE WEIGHT:

Preliminary weight estimates of the CMM configurations shown in Figures 1 and 2 have been made an are listed in Table 2. The weight estimates are given as a function of various missions; these missions bounding the proposed matrix of advanced missions listed in the introduction of this memorandum. Bulkhead weights are very sensitive to the assumed CMM geometry and variations ranging within an order-of-magnitude are possible. It is felt, however, that the toroidal configuration assumed in this memorandum is realistically representative of the expected weight penalty.

A large portion of the structural weight is attributed to the CMM outer wall and is a function of the proposed mission; this variation being primarily due to the meteoroid/asteroid environments. Using the meteoroid environment as specified in Reference 2 and the Charters and Summers penetration theory, along with a criterion of P (0) = 0.999, the required thin-sheet weight of aluminum can be determined as a function of exposed CMM cylindrical surface area and mission duration. However, the outer wall of the CMM is not a thin sheet of aluminum; it is a complex structure. Therefore, an appropriate bumper factor should be used to estimate outer-wall weights. Various bumper factors have been proposed ranging as high as 20 for missions in the early 1970's. However, it is not unrealistic to assume that bumper factors of only 5 or so may actually be used when meteoroid shielding is considered in context with all the requirements of a CMM outer wall. (Reference 5). A lower cutoff point exists for outer-wall structure density. Assuming a truss core where the face sheets are spaced at an effective distance for meteoroid bumper shielding, a minimum thickness exists to prevent local and gross buckling due to boost loads during launch into Earth orbit. Also, the "third" sheet or CMM pressure wall must be thick enough to withstand internal cabin pressure. If there were no meteoroid/asteroid environments to withstand, the outer wall could be designed differently and for less weight. It could, for instance, be pressure stabilized. Applying the above bumper factor, the outer-wall weight density for missions in space other than the asteroid belt are shown in Figure 5. Lower cutoff points to outer-wall weights as well as estimated meteoroid shielding weights were investigated in detail by the Boeing Company, Seattle, and are reflected in Figure 5. Briefly, the outer-wall weight penalties for a 2 and 5 year mission duration, for the CMM configurations in Figures 1 and 2 are

TABLE 3

Mission (years)	1-Floor Weight $(\frac{lbs}{ft^2})$	2-Floor Weight $(\frac{lbs}{ft^2})$
2	3.5	4.2
5	4.8	5.6

TABLE 2

PRELIMINARY STRUCTURAL WEIGHT BREAKDOWN
OF A ONE AND TWO-FLOOR COMMON MISSION MODULE

ITEMS	1-Floor Weight(lbs)	2-Floor Weight(lbs)
1. Outer Wall/Missions		
• 2 Yr. Meteoroid	2380	4580
• 5 Yr. Meteoroid	3260	6100
• 8 Mo. Asteroid	5300	10900
2. 2-Bulkheads	1383	1383
3. 2-Field Joint Rings (6x4x1/4 inch box section,AL.)	816	816
4. 2-Support Rings (6x4x1/8 inch tee-section equivalence,AL)	750	750
5. Hatches (2-outer and 1-airlock)	300	300
6. Central Airlock (3.5 ft dia. x 0.05 inch,AL.)	79	126
7. Beams and Flooring* (0.10 inch,AL. plate equivalence)	905	1358
8. Diagonal Tension Ties (10-1/4 inch flex. corosion res. cables)	106	170
9. Total of Items 2→8	4339	4903
10. Contingency, 10% of Item 9	434	490
11. Total Weight (Items 1 + 9 + 10)		
• 2 Yr. Meteoroid	7153	9973
• 5 Yr. Meteoroid	8033	11493
• 8 Mo. Asteroid	10073	16293

*Whether or not item 7 is "required" is not as yet determined.

Considering the maximum asteroid flux model proposed by MSC
based on calculations of the Gegenshein phenomenon, a
P (0) = 0.999 design criterion, and a bumper factor of 5.0,
the outer-wall weight penalties for missions through the
asteroid belt can be estimated and are also shown in Figure
5. The weight penalty associated with a Mars twilight flyby
mission, 240 days in the asteroid belt, is approximately

$$\text{1-floor CMM} \rightarrow \text{weight} \simeq 7.8 \frac{\text{lbs}}{\text{ft}^2}$$

$$\text{2-floor CMM} \rightarrow \text{weight} \simeq 10.0 \frac{\text{lbs}}{\text{ft}^2}$$
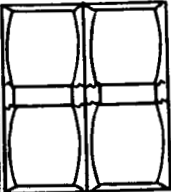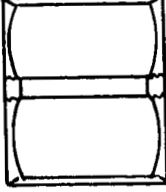
V.   VARIATION OF CMM STRUCTURE WEIGHT WITH RESPECT TO ONE
     AND TWO FLOOR CONFIGURATIONS AND NUMBER OF ASTRONAUTS:

          A matrix showing the parametric effects of consider-
ing one and two-floor mission-module building blocks as a func-
tion of the number of astronauts is shown in Table 4. This
matrix is for a 2-year mission in space that does not pass
through the asteroid belt. Included in the matrix are the CMM
parameters

          a.   Length,
          b.   Total pressurized volume, and
          c.   Structural weight.

A one-floor CMM building block shows a structural weight advan-
tage of 2,820 lbs. with respect to two-floor module. However,
there is a distinct advantage, weight wise (2,593 lbs. to
5,693 lbs.) for using a two-floor CMM building block for mis-
sions requiring 4 to 12 astronauts. Since advanced planetary
studies are currently heavily weighted towards missions re-
quiring 4 astronauts or greater,it appears, based on structural
weight only, that two-floor CMM building blocks are more advan-
tages than one-floor modules. However, the several thousand pound
penalty associated with the use of the smaller module on larger-
scale missions may greatly increase the utilization of the basic
unit through application in Lunar and Synchnonous Earth-orbital
missions.

TABLE 4 - CMM PARAMETERS VS. CREW SIZE FOR A 2-YEAR MISSION (DOES NOT PASS THROUGH THE ASTEROID BELT)

PARAMETER	LENGTH (ft)			PRESSURE CAN VOLUME (ft³)			STRUCTURAL WEIGHT (lbs)*		
CREW SIZE	2-3	4-6	8-12	2-3	4-8	8-12	2-3	4-6	8-12
1 Floor per can Common Module (Used in Multiples) — NUMBER OF CANS	1	2	3	1	2	3	1	2	3
	10	20	30	2658	5316	7974	7153	15666	24719
2 Floors per can Common Module (Used in Multiples) — NUMBER OF CANS	1	1	2	1	1	2	1	1	2
	16	16	32	4656	4656	9312	9973	9973	22126

*NOTE: Estimates are not simple multiples, since meteoroid shielding requirements vary with respect to exposed surface area.

VI. **CONCLUSIONS:**

1. The total structural weight of a one and a two-floor CMM (see Figure 1) can be estimated as

TABLE 5

MISSION	1-Floor Weight (lbs)	2-Floor Weight (lbs)
2 yr. meteoroid	7153	9973
5 yr. meteoroid	8033	11493
8 mo. asteroid belt.	10073	16293

2. A one-floor CMM is more advantageous weight-wise (structural), than a two-floor CMM for missions requiring 2 to 3 astronauts.

3. A two-floor CMM is more advantageous weight-wise (structural) than a one-floor CMM for missions requiring 4 to 12 astronauts.

4. The several thousand pound penalty, associated with using one-floor CMM building blocks, on planetary missions requiring $\gtrsim$ 4 astronauts is

    approximately 4% or less of the injected payload. Whereas, the weight advantage, associated with a 2 to 3 man CMM, for relatively short-lived lunar bases, represents 5% or more of the landed payload, and perhaps 25% of the useful payload.

C. E. Johnson

Attachments
  Figure 1-5

BELLCOMM, INC.

REFERENCES

1. Davenport, E. W., Congdon, S. P., and Pierce, B. F.,
   "The Minimum Volumetric Requirements of Man in Space,"
   AIAA Summer Meeting, Los Angeles, California,
   June 17-20, 1963.

2. Orrok, G. T., "Meteoroid Environment Changes to the
   Apollo Document: Natural Environment and Physical
   Standards for the Apollo Program, M-DE 8020.008B
   (SE 015-001-1), April, 1965, Bellcomm Memorandum for
   File, ated April 18, 1966.

3. Johnson, C. E., "Technical Discussions with Ed Lupo of
   MSC Concerning Meteoroid/Asteroid Design of a Manned Mars
   Flyby Spacecraft per the March 28, 1967 JAG Meeting,"
   Bellcomm Letter to C. L. Davis, dated April 20, 1967.

4. Johnson, C. E., "Comments Concerning Meteoroid/Asteroid
   Spacecraft Design Policy for a Manned Mars Twilight Flyby
   Mission," Bellcomm TM-67-1013-4, October 11, 1967.

5. Allesina, B., and Woodhead, G. E., "Study of Cost Effective
   Structures Design for Future Space Systems," NAS7-525,
   Progress Report #3, The Boeing Co., Seattle, Washington,
   April, 1967.

6. Skeer, M.H., "Structural Configuration of the Integrated
   Mission Module," Letter to J. M. Tschirgi, dated
   September 21, 1967.

7. Johnson, C.E., "Comments on Design Policy for the Use of
   Radiators in a Meteoroid/Asteroid Environment for Advanced
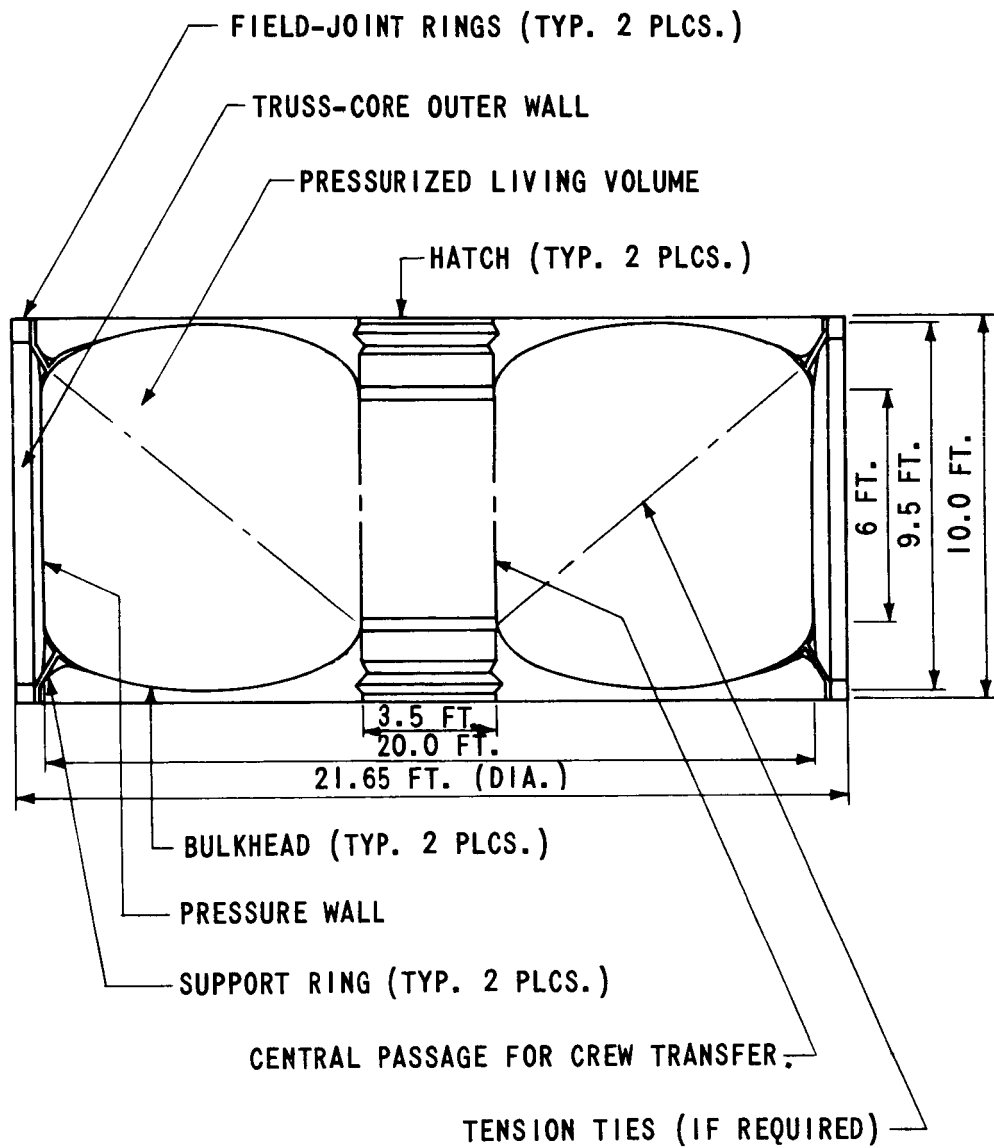   Missions, Bellcomm Memorandum for File, to be issued.

FIELD-JOINT RINGS (TYP. 2 PLCS.)

TRUSS-CORE OUTER WALL

PRESSURIZED LIVING VOLUME

HATCH (TYP. 2 PLCS.)

6 FT.

9.5 FT.

10.0 FT.

3.5 FT.

20.0 FT.

21.65 FT. (DIA.)

BULKHEAD (TYP. 2 PLCS.)

PRESSURE WALL

SUPPORT RING (TYP. 2 PLCS.)

CENTRAL PASSAGE FOR CREW TRANSFER.

TENSION TIES (IF REQUIRED)

FIGURE 1 - 1-FLOOR COMMON-MISSION-MODULE CONFIGURATION

FIELD-JOINT RINGS (TYP. 2 PLCS.)

TRUSS-CORE OUTER WALL

PRESSURIZED LIVING VOLUME

HATCH (TYP. 2 PLCS.)

12.0 FT.

15.5 FT.

16.0 FT.

3.5 FT.

20 FT.

21.65 FT.

BULKHEAD (TYP. 2 PLCS.)

PRESSURE WALL

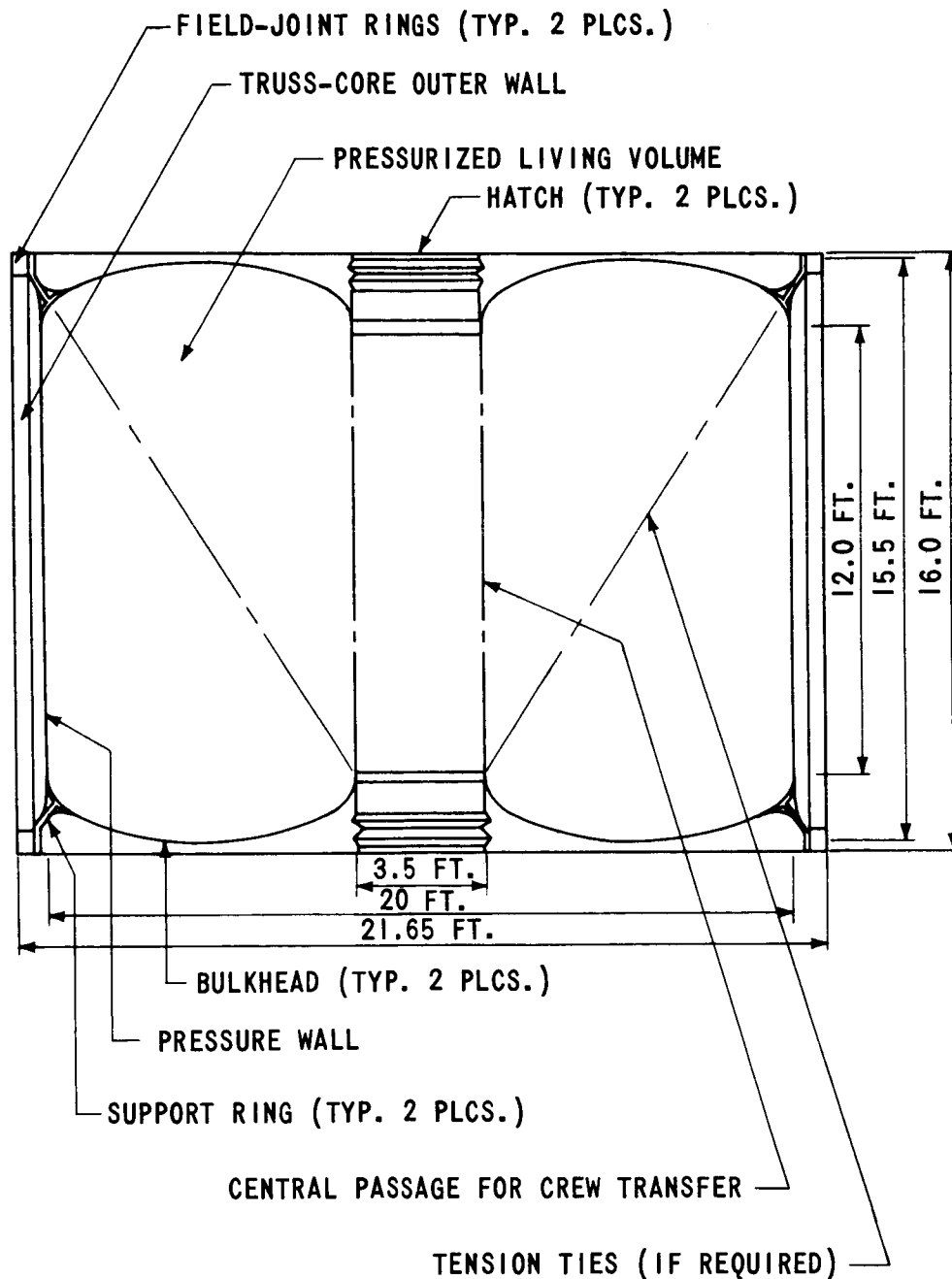SUPPORT RING (TYP. 2 PLCS.)

CENTRAL PASSAGE FOR CREW TRANSFER

TENSION TIES (IF REQUIRED)

FIGURE 2 - 2-FLOOR COMMON-MISSION-MODULE CONFIGURATION
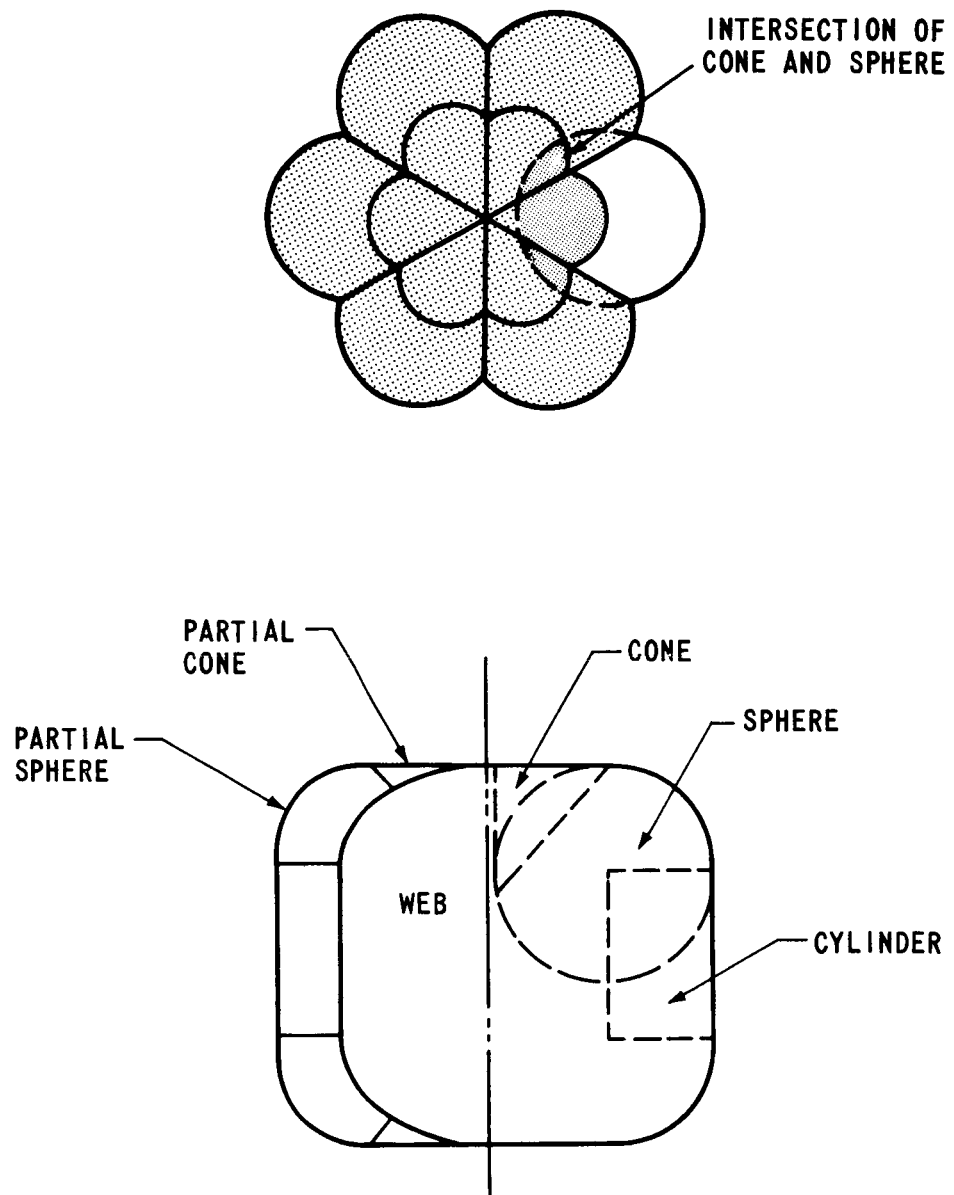
FIGURE 3 - SIX SEGMENT SCALLOP MISSION MODULE CONFIGURATION

RADIATOR

METEOROID BUMPER

MULTI-SHEET INSULATION

LOAD CARRYING
TRUSS-CORE

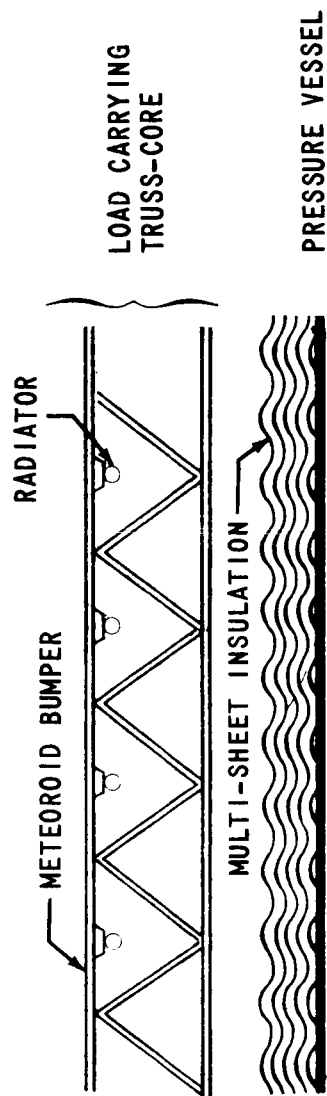PRESSURE VESSEL

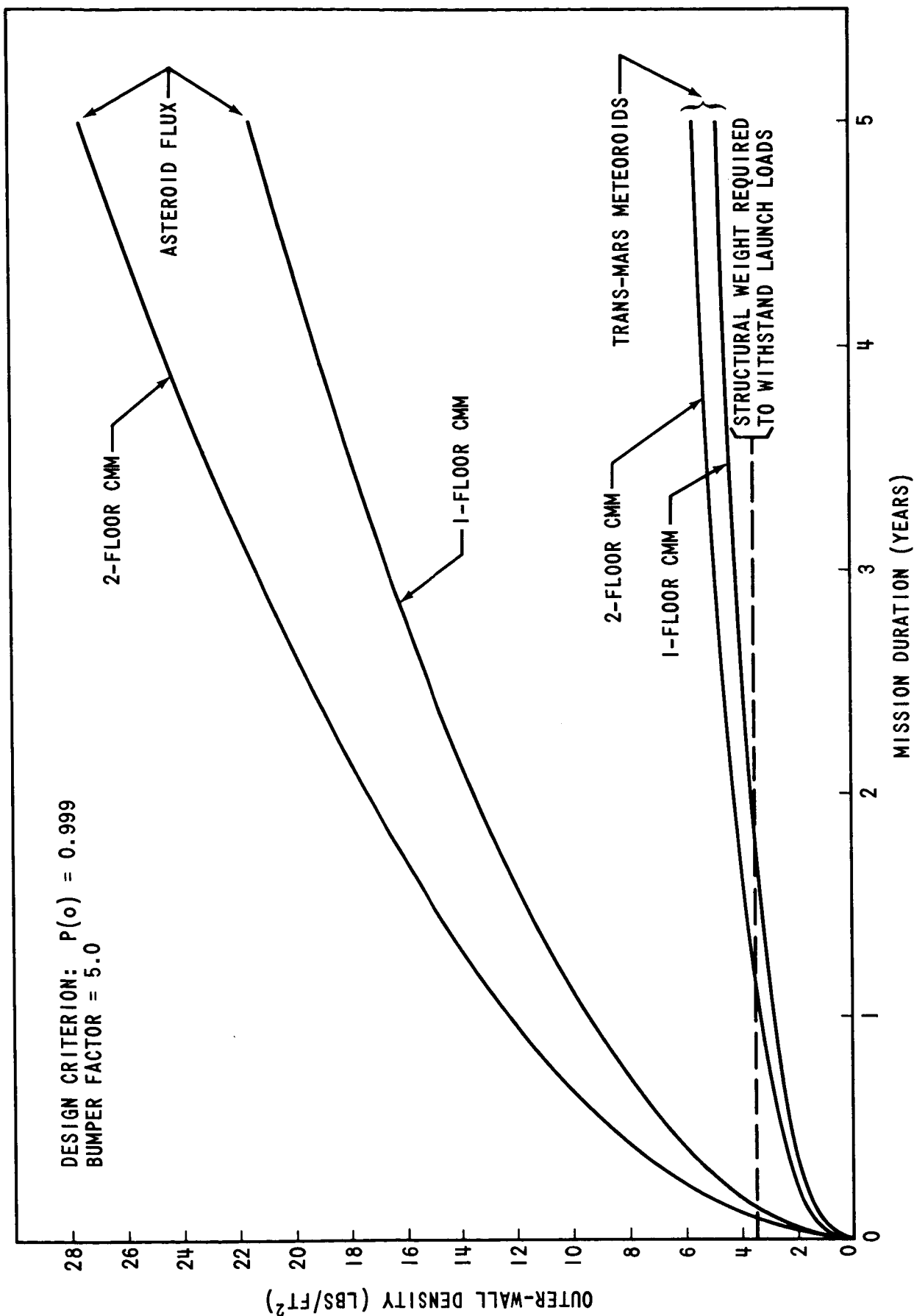FIGURE 4 - COMMON-MISSION-MODULE OUTER-WALL CONFIGURATION

FIGURE 5 - PLOT OF OUTER-WALL DENSITY vs. MISSION DURATION FOR A 1-FLOOR AND A 2-FLOOR COMMON MISSION MODULE WITH RESPECT TO AN ASTEROID AND A TRANS-MARS METEOROID FLUX ENVIRONMENT

BELLCOMM, INC.

Subject: Weight Estimates of Common Mission   From: C. E. Johnson
Module Structure - Case 730

DISTRIBUTION LIST

NASA Headquarters

Messrs. P. E. Culbertson/MLA
       F. P. Dixon/MTY
       E. W. Hall/MTS
       T. A. Keegan/MA-2
       R. L. Lohman/MTY
       D. R. Lord/MTD
       M. J. Raffensperger/MTE
       A. D. Schnyer/MTV

MSC

Messrs. C. Covington/ET23
       G. C. Miller/ET23
       E. H. Olling/ET4
       W. E. Stoney/ET4
       H. K. Strass/ES13

Bellcomm, Inc.

Messrs. F. G. Allen
       G. M. Anderson
       A. P. Boysen, Jr.
       C. L. Davis
       J. P. Downs
       D. R. Hagner
       P. L. Havenstein
       W. C. Hittinger
       B. T. Howard
       D. B. James
       H. S. London
       K. E. Martersteck
       R. K. McFarland
       J. Z. Menard
       I. D. Nehama
       G. T. Orrok
       I. M. Ross
       J. M. Tschirgi
       R. L. Wagner
       J. E. Waldo
All Members, Division 101
Central File
Department 1023
Library